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RESEARCH

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DIVISION OF  
TELECOMPUTING CORPORATION  
3850 OLIVE STREET, DENVER 7, COLORADO, DUDLEY 8-4836

## SILVER-CADMIUM BATTERY DEVELOPMENT PROGRAM

### QUARTERLY TECHNICAL PROGRESS REPORT

FOR FIFTH QUARTER, ENDING 20 NOVEMBER 1962

DATED

17 December 1962

CONTRACT NO. NAS5-1431

### OTS PRICE

XEROX	\$	<u>4.60 ph</u>
MICROFILM	\$	<u>1.64 mf.</u>

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<sup>2</sup>  
223 8392 POWER SOURCES DIVISION  
Telecomputing Corporation, Denver, Colo.

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17 Dec. 1962

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## TEST PROCEDURE

CONFERENCES

A conference was held at Power Sources Division of Telecomputing Corporation, Denver, Colorado, on September 24, 1962.

Those present were:

NASA - Mr. T. J. Hennigan

Power Sources - Mr. J. W. Rhyne, Jr.  
- Mr. J. M. Rice

The current status of the program was discussed. This included proposed testing procedures and battery connector design, as well as the progress made toward the successful conclusion of the project.

## REPORT

### PHASE I - CONTAINER DESIGN AND DEVELOPMENT

#### Cell Case

The final cell case material has been selected. In the last report, attention was being given to the evaluation of four systems: Styrene; Styrene coated with Saran F-120; Saran F-120; Epoxy-polyamide. Of these, Styrene and epoxy-polyamide were felt to be applicable, since Saran had previously been found to be electrochemically incompatible. Subsequently, epoxy-polyamide was found to precipitate free silver from an alkaline solution of silver oxide at 120°F. The reaction was not noted at room temperature. The material chosen therefore, was Tyril 767, a styrene-acrylonitrile copolymer, which was found to be electrochemically inert under the proposed operating conditions.

The final cell case design is shown as Figure 1. This is an injection molded piece with provision for plate lead wires and a filling port and plug. Cases, lids, spacers and plugs have been molded for production of the batteries called for in the program.

#### Container Fabrication

Battery Case Number 10\* was subjected to two tests:

1. Air Pressure Test

The battery was immersed in water and an internal air pressure of 75 psig was applied for a period of five minutes. No leakage was detectable.

2. KOH - Permeability Test

The battery case was filled with a 40% by weight aqueous potassium hydroxide solution and held at a constant pressure of 75 psig with nitrogen at a temperature of 115 - 125°F for a period of eight days. A daily weight determination was made. The results were plotted in Figure 2 and tabulated below in Table I. A diagram of the test apparatus is shown in Figure 3.

\* For details of construction see Quarterly Report dated 14 September 1962

Prior to a vibration test, it was discovered that Case Number 10 had delaminated at the Teflon interface due to clamping pressure exerted by the vibration fixture. For this reason, Case Number 10 was not subjected to vibration. Additionally, the change of cell case material from epoxy-polyamide to styrene necessitated further study of the bonding systems involved.

Case Number 11 was wound using styrene cell containers, but otherwise was the same as Case Number 10. After curing overnight at 150°F, it was noted that delamination had occurred at the styrene-epoxy-Teflon interface. The cause of failure was found to be the styrene-epoxy bond. A bonding study was initiated in which several systems were investigated (Tables II through IV).

Initial evaluations verified the superiority of the polyurethane system, especially when used as a primer for the epoxy-polyamide system.

Battery Case Number 12, therefore, was wound in the same manner as Number 11, with the exception of using the polyurethane primer. The following procedure was followed:

A. Mandrel Assembly

1. Molding styrene-acrylonitrile cell cases.
2. Packing cell cases with 1/16" neoprene and lead sheet to a simulated final active cell weight.
3. Bonding and curing lids to cell cases with catalyzed styrene monomer cement.
4. Bonding eleven dummy cell cases together with catalyzed styrene monomer cement and curing for ten hours at 100°F.
5. Potting the segment with Metlbond 3135 (epoxy-polyamide).
6. Assembly of end-plates to cell cases using Metlbond 3135 (done together with Item 4).
7. Grinding the entire assembly to a uniform O. D. This also removed any mold release, and provided a fresh surface to which to bond.

B. Battery Case Winding

1. Preparation of the surface by cleaning with isopropanol.
2. Application and cure of 2 mils of polyurethane prime coat.
3. Assembly was then lathe mounted, and the resin-Epon 820 (80 pts), Lancast A (20 pts) was applied, leaving one end temporarily dry.
4. A few drops of Eastman 910 adhesive were applied to the starting end of the Teflon FEP Tape (2 mil x 1 inch) to secure the tape to the dry end of the mandrel and provide tape winding tension. The epoxy was then applied up to the tape adhesive joint.
5. The tape was then spirally wrapped with an approximate 1/4 inch lap joint. A brush coat of the 80-20 epoxy was applied over the tape during this operation.
6. Filament winding using 150/MTS single-end glass roving impregnated with epoxy-polyamide (50% Epon 820, 50% Lancast A).
  - a. Teflon tied down with circular wrapping about 3/4 inch wide at both ends of the case at an approximate tension of 1/2 pound.
  - b. One layer wound at 40° and 140° angles to the battery axis.
    - (1) Mandrel rotation - 56 rpm.
    - (2) Traverse count - 28 per minute.
  - c. Two additional layers similar to "b". Total traverse count for the three layers - 741.
  - d. One layer of circular wrappings full length at a longitudinal speed of 0.0083 inch/revolution.
  - e. One layer of circular wrappings approximately one inch wide at both ends.
  - f. Brush application of resin, followed by a light squeegee to form a continuous surface.

7. The assembly was initially gelled under constant rotation for two hours, followed by the application of heat while rotating not to exceed 125°F.
8. The battery was removed from the lathe, and oven cured at 125°F for fourteen hours.

The final weight of the filament wound shell and tape liner was 51 grams, excluding end plates. The lengthwise shrinkage after cure was 0.46%.

#### Testing of Battery Case Number 12 (Dummy Battery Number 2)

##### 1. Air Pressure Test

The dummy battery, Case Number 12, was subjected to the air pressure test as described on page 2. No leakage was detected.

##### 2. Low Temperature Test

The battery was soaked for three hours at -20°C. After removal, it was checked for possible voids. The potted segment was found to have separated from the styrene at one end. It was elected to continue the scheduled tests at this time.

##### 3. KOH - Permeability Test

The battery was subjected to the KOH - Permeability Test as described on page 2. Due to the time lost on Cases 10 and 11, only the first three points were read for conformity to the previous curve, Figure 4. The permeability change is shown in the following table:

<u>Elapsed Time</u> <u>Days</u>	<u>Weight Increase, Grams</u> <u>per 24 Hours</u>
1	0.0921
2	0.0749
3	0.0544

By extrapolation of the curve, it appears that an equilibrium of about 0.033 grams/day will be reached after eight days.

At this rate, the daily loss would be 0.58 grams/square meter (total case area is 0.076 m, 0.203 m = 0.057 m<sup>2</sup>), or about 40% of the acceptable level of 1.5 gm/day/m<sup>2</sup> as originally specified.

#### 4. Vibration and Leak Rate Determinations

Helium leak checks were run before and after vibration. The initial leak rate was found to be  $5.42 \times 10^{-5}$  cc air/sec.

The battery was cycled from 5 to 3000 cps and back to 5 cps during a nine minute period at an applied acceleration of  $\pm 20$  g, and a maximum double amplitude of 0.4 inches. Crossover was at 31 cps. Vibration was on each of three mutually perpendicular axes. There were no battery resonances observed, and no visible failures. After vibration, the rate had become  $7.07 \times 10^{-5}$  cc.

#### 5. Burst Test

The assembly was then pressurized to destruction. Case rupture occurred at 550 psi.

TABLE I

<u>Elapsed Time - Days</u>	<u>Test Drying Flask J - Grams Increase in Weight</u>	<u>Control Drying Flask - Grams Increase in Weight</u>	<u>Total Net Increase in Weight Grams J - I</u>	<u>Increase in Weight Per 24 Hours</u>
1	.2074	.0738	.1336	.1336
2	.2874	.0933	.1941	.0605
3	.3258	.0984	.2325	.0384
4	.3638	.1046	.2592	.0267
5	.3970	.1088	.2882	.0290
6	.4226	.1110	.3116	.0234
7	.4517	.1151	.3366	.0250
8	.4702	.1161	.3541	.0175

TABLE II**EXPERIMENT NUMBER 1**

**SPECIMEN:** 5 mil Teflon FEP, Type 544 bonded to Tyril 767 molded sheet.

**TEST:** Teflon peeled by hand from the styrene.

**STYRENE PREPARATION:** 1. Degrease with isopropyl alcohol; 2. Dry sand with 400 A carborundun paper; 3. Degrease with isopropyl alcohol.

**TEFLON PREPARATION:** None

**CURE CONDITIONS:** 48 hours at Room Temperature

ADHESIVE SYSTEM	SPECIAL CONDITIONS	TEST RESULTS AND COMMENTS
1. Epon 820/Lancast A, 50/50	None	Fair peel
2. Epon 820/Lancast A, 80/20	None	Good peel - rank #3
3. Epon 828/Versamide 125, 50/50	None	Poor peel - failed to styrene
4. Power Sources Styrene Cement	None	Poor peel - failed to Teflon
5. PolyLite 8037, MEK peroxide (1 phr)*	None	Poor peel - failed to Teflon
6. Narmco R & D - X305	None	Very good - rank #1
7. Epon 828/Versamide 125/Styrene Monomer 50/50/5	None	Poor peel - failed to styrene
8. Adiprene L-100, Moca (11 phr)*	None	Good peel - rank #4
9. Same as No. 3	10 min. @150°F etch in a bath composed of 30 pts H <sub>2</sub> O, 10 pts H <sub>2</sub> SO <sub>4</sub> , 4 pts Na <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> distilled H <sub>2</sub> O rinse, 10 min. @ 180° dry	Good peel - rank #2
10. Same as No. 3	Primed with styrene monomer, 15 min. air dry	Poor peel - failed to styrene
11. Same as No. 4	Same as No. 9	Poor peel - failed to Teflon
12. Same as No. 4	Same as No. 10	Poor peel - failed to Teflon

\* Per hundred parts of resin

TABLE III

## EXPERIMENT NUMBER 2

**SPECIMEN:** Various Films bonded to Tyril 767 molded sheet

**TEST:** Film peeled by machine at 180° to styrene sheet

**STYRENE PREPARATION:** Sand with 400A carborundun paper, degrease with isopropyl alcohol.

**FILM PREPARATION:** None

**CURE CONDITIONS:** 4 hours at 125° F

ADHESIVE SYSTEM	FILM	SPECIAL CONDITION	180° PEEL, lbs/in.
1. Epon 820/Lancast A, 80/20	Teflon FEP, Type 544, 5 mil	None	3.0
2. Narmco R & D X-305	Same as No. 1	None	Too poor to test
3. Adiprene L-100, Moca (11 phr)	Same as No. 1	None	10.5
4. Same as No. 1	Same as No. 1	NaCr <sub>2</sub> O <sub>7</sub> etch	8.0
5. Polylite 8037, MEK peroxide (1 phr)	Saran, 1/2 mil	None	Too poor to test
6. Power Sources Styrene Cement	Same as No. 5	None	Too poor to test
7. Same as No. 1	Same as No. 5	None	Too poor to test
8. Same as No. 5	Mylar, 5 mil	None	Too poor to test

TABLE IV

## EXPERIMENT NUMBER 3

**SPECIMEN:** 5 mil Teflon FEP, Type 544 bonded to Tyril 767 molded sheet.

**TEST:** Film peeled by machine at 180° to styrene sheet.

**STYRENE PREPARATION:** Sand with 400A carbonundum paper, degrease with isopropyl alcohol.

**PRIME:** Adiprene L-100, Moca (11 phr) brush coated, uncured, or cured 20 minutes at 212°F.

**FILM PREPARATION:** None

**CURE CONDITIONS:** 4 hours at 125°F

ADHESIVE SYSTEM	PRIME	180° PEEL, lbs/in.
1. Epon 820/Lancast A, 80/20	Styrene coated cure	Very good, but could not be tested due to Teflon failure
2. Epon 820/Lancast A, 80/20	Styrene coated, not cured	3.0
3. Epon 820/Lancast A, 80/20	Teflon coated, cured	5.0
4. Epon 820/Lancast A, 80/20	Teflon coated, not cured	4.5
5. Epon 820/Lancast A, 80/20	Teflon and Styrene coated, cured	6.5
6. Epon 820/Lancast A, 80/20	Teflon and Styrene coated, not cured	9.5

## PHASE II - ELECTROCHEMICAL DESIGN

During this report period, several types of cell constructions were evaluated for the purpose of selecting a prototype design. The various configurations are shown in Figure 5. These cells are identified as K, L and M. All three had the following elements in common:

Number of positive plates	5
nominal thickness (each)	.012 inch
Number of negative plates	6
nominal thickness (each)	.020 inch
Area per side	4 in <sup>2</sup>
Separator system	1 layer Dynel - non-woven
	1 layer polyethylene base ion exchange membrane
	4 layers modified cellophane
	1 layer Dynel - non-woven

### Cell K

In this configuration, the negative plate was first heat sealed in a Dynel envelope, and then was subassembled into a package consisting of four layers each of modified cellophane cemented to each side of a compression ring. The positive plate was heat sealed in an envelope consisting of one inner wrap of Dynel and one outer wrap of the polyethylene membrane. One positive envelope was then positioned between two negative subassemblies to the total configuration listed above. This was an extension of the configuration of cells I and J. The seal was made at the cemented ring-separator joint.

### Cell L

Positive and negative plates for this cell were made up in envelopes as described above. However, each plate (positive and negative) was positioned inside a compression ring, making a total of eleven rings. Four layers of the modified separator were placed between each ring -- a total of ten four-layer packs. The seal system was ring/separator (four layers).

### Cell M

Plates for cell M were made in envelopes as described for cell K. The distinction in this case was that instead of the alternate ring-separator system, described for cell L, the rings were doubled. In effect then, the seal was separator to separator at the positive plate, with the negative plate positioned between the double rings.

Five cells were made similar to cell M for group electrical cycling.

### Test Results

#### Cells E and F

These cells were made to further check the feasibility of the bipolar plate for this type use. The construction of these cells was reported in the Second Quarterly Report. It was found in cell E that interaction between the cadmium and silver oxide (AgO) occurred through the silver diaphragm grid. Reduction of the silver oxide to free silver occurred at the interface between the sheet silver and the silver oxide. Oxidation of the cadmium to cadmium hydroxide occurred at sites opposite to those areas of maximum silver oxide reduction. Analysis of the silver oxide for AgO content indicated that a 20% reduction in capacity had occurred. This did not take into account the layer which had been reduced to free silver. Semi-quantitative determination made on the cadmium material indicated that a similar change had occurred. Since this test was conducted under stand conditions, it may be extrapolated that the degree of self discharge would be enhanced under actual charge conditions.

Analysis of cell F (Platinum foil grid) gave results that indicated no effect such as reported above other than normal decomposition of the divalent silver oxide to monovalent oxide in alkaline solution.

#### Cell J (Fourth Quarterly Report)

This cell was placed on automatic cycle, with a constant potential charge at 1.56 volts for 55 minutes and a constant current discharge at 1.0 amperes. Charge current was limited to 1.0 amperes. This schedule was followed for 124 cycles. At that time a change was made so as to combine two cycles, thus giving one cycle a day with a 120-minute charge and a 60-minute discharge, as well as 14 cycles of the 55 - 35 minute deviation.

The cycle history of this cell is shown in Table V. Typical voltage and current curves for the two length cycles are shown in Figures 6 and 7.

After 214 cycles, the cell was taken apart to determine the status of the internal components. Of particular interest was the condition of membrane seal around the positive plates. The spacer rings were slightly undersize on this cell, thus providing minimum compression of the membrane layers. There was no evidence of silver migration except in one area in which the surface irregularity of a ring provided no seal.

#### Cells K, L and M

Cells K, L and M were initially manually cycled to assure proper initial operation. Cell K was not placed on automatic cycle due to similarity in construction to cells J and M. Cells L and M were cycled on the schedule shown in Table V. These cells were cycled alternately. Cell K exhibited electrical characteristics identical to those of cells J and M under the load conditions imposed. Cell M was cycled for a total of 148 cycles at the rate of fourteen - 90-minute and one - 180-minute cycles a day with a 1.0 ampere constant current discharge and a 1.0 ampere limited, 1.56 volt constant potential charge. The cell was then manually cycled to determine the effective capacity. After this, a four-hour cycle was used at a 1.5 ampere discharge rate. The cycle time was 150 minutes' charge and 90 minutes' discharge. After 18 cycles the charge to discharge times were changed to 135 minutes' charge and 105 minutes' discharge. This represented a fairly severe cycle since the discharge was at 1.5 amperes constant current with a 1.5 ampere limited constant potential recharge. Typical performance of cell M under the 180-minute and the four-hour (105-minute discharge) cycles are shown in Figures 8 and 9.

#### Prototype Cells (P-1 to P-5)

These cells were manually cycled at increasing rates of discharge until sufficient capacity had developed to permit automatic cycling. The charge was a 5.0 ampere current limited constant potential charge at 7.80 volts for the group of five cells. Discharge was made through a fixed resistance of 1.21 ohms. The time cycle was approximately 55 minutes of charge and 35 minutes of discharge for a total of 16 cycles per day. Typical current curve for a cycle is shown as Figure 10. As of the closing date of this report these cells are on continuing cycle.

TABLE V  
CYCLE SCHEDULE, CELLS J, L AND K

	<u>No. Cycles/ Day</u>	<u>CP Charge Time</u>	<u>Discharge</u>		<u>Total Cycles</u>
			<u>Time</u>	<u>Current</u>	
Cell J	16	55	35	1.0	124
	14	55	35	1.0	84
	1	120	60	1.0	<u>6</u>
					214
Cell L	14	55	35	1.0	247
	1	120	60	1.0	18
	Manual	-	-	1.5	<u>3</u>
					268
Cell M	14	55	35	1.0	137
	1	120	60	1.0	11
	Manual	-	-	1.5	2
	6	150	90	1.5	18
	6	135	105	1.5	<u>30</u>
					198

### PHASE III - PROTOTYPE FABRICATION AND TESTING

During this period a prototype cell design was finalized and released to manufacturing, Figure 11. Cells made to this design in the laboratory are cycling normally after approximately 500 cycles. The details of construction are as follows:

Number of positive plates	5
Number of negative plates	6
Area per side	4 in <sup>2</sup>
Separator system	1 layer Dynel - non-woven 1 layer polyethylene base ion exchange membrane 4 layers modified cellophane 1 layer Dynel - non-woven

The positive plate is made as a heat sealed envelope consisting of Dynel and polyethylene. This is packed between eight layers of the modified cellophane which are mechanically sealed by means of compression rings. The negative plate is heat sealed in a Dynel envelope, and is centered between the compression rings.

The silver wire leads are twisted and spot welded in the area which is positioned in the case slot. This was done to prevent wicking of the electrolyte in the wire bundle through the seal area. Additional sealing is provided outside the cell case by encapsulating the intercell connections with catalyzed styrene monomer cement.

Following the sealing of the leads and cell case lids, an initial conditioning cycle period is employed in which the rate and depth of discharge is increased through twenty-five cycles. The cells are then sealed in accordance with the following procedure:

1. The cell is placed in a vacuum chamber in which provisions are made for gas inlet and mechanical seal plug manipulator as well as connection to a vacuum pump.

2. A bead of catalytic styrene cement is placed around the edge of the fill port.
3. The seal plug is placed in the holder and positioned over the fill port.
4. The atmospheric pressure in the cell and chamber is reduced to less than 20" Hg vacuum.
5. A 10 - 90 mixture of Helium and Nitrogen gases is then admitted to restore normal pressure.
6. Steps 4 and 5 are repeated an additional two times to insure the replacement of entrapped air within the cell.
7. The pressure is then reduced to a vacuum of 20" Hg (approximately 3 psia) and the seal plug seated under mechanical pressure.
8. Normal atmospheric pressure is then restored within the chamber and the cell removed and placed in a clamp to permit full setting of the cement. Pressure differential across the plug prevents loosening during the brief time of no mechanical pressure.

Upon completion of the cure of the cement, the cells will be leak checked by the use of a Consolidated Electrodynamics Corporation Type 24-120 Helium Leak Detector.

The cells will then go to final assembly, where they will be cemented together, electrically balanced, connected and potted. A drawing of the final assembly, prior to winding, is shown as Figure 12.

#### Prototype Testing

Test Procedure 60219 is enclosed as an attachment to this report. This test procedure will be used in conducting the battery test program.

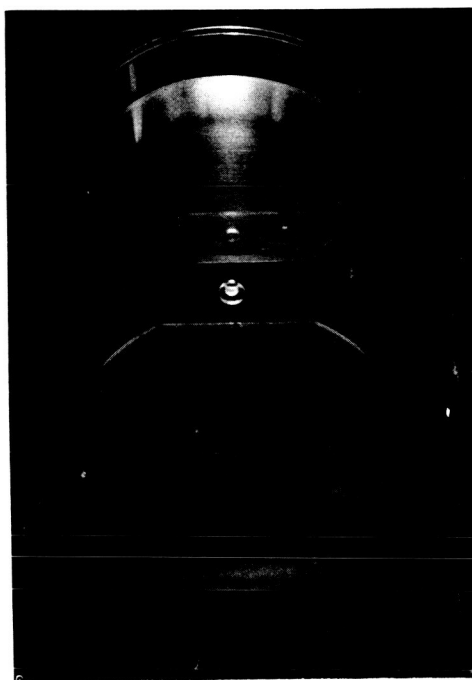
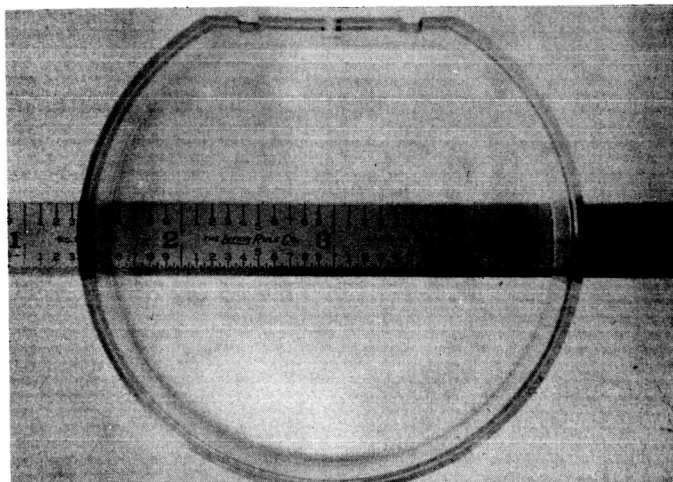


Figure 1. Final Cell Case Design

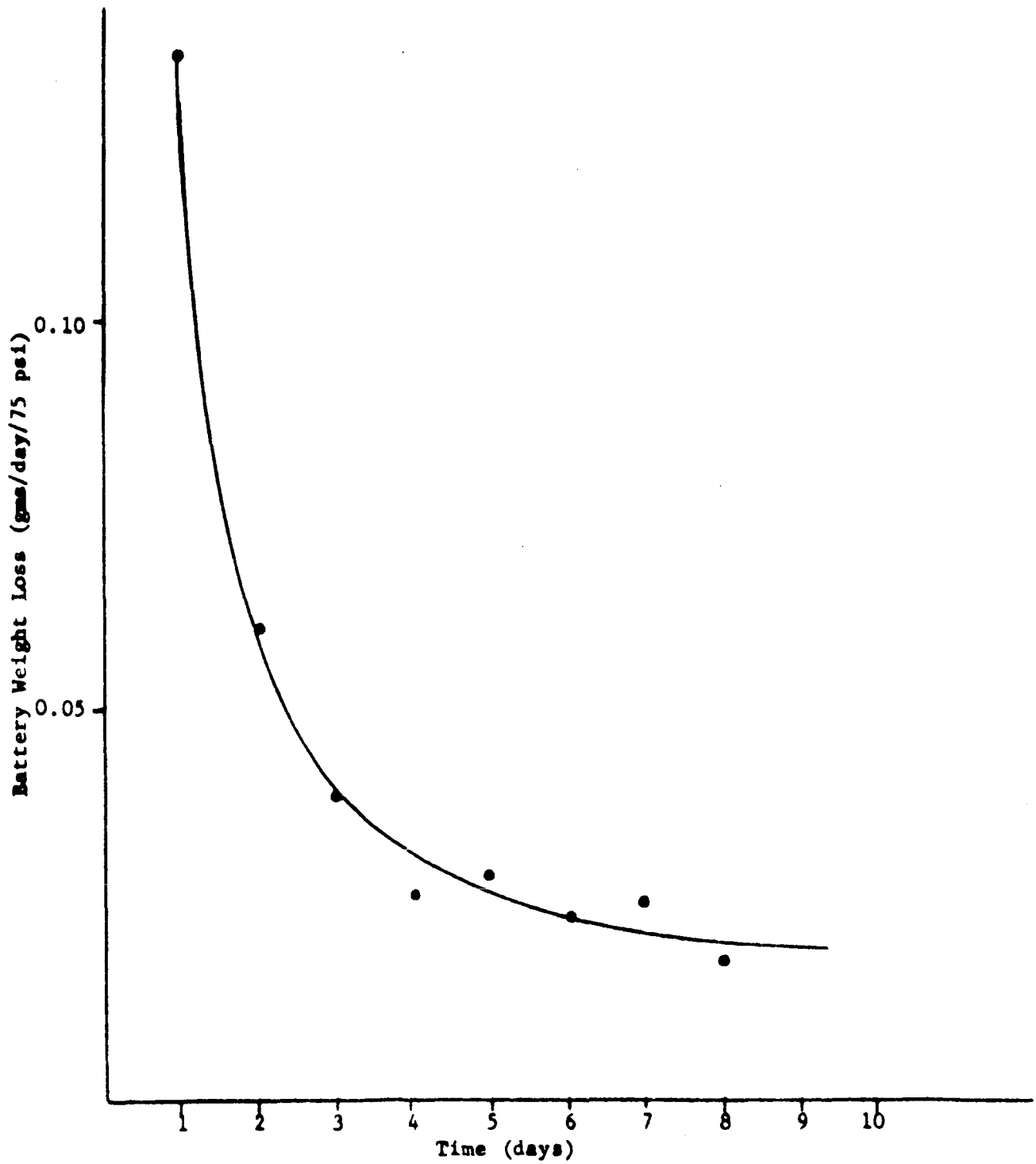


Figure 2. KOH Permeability Test

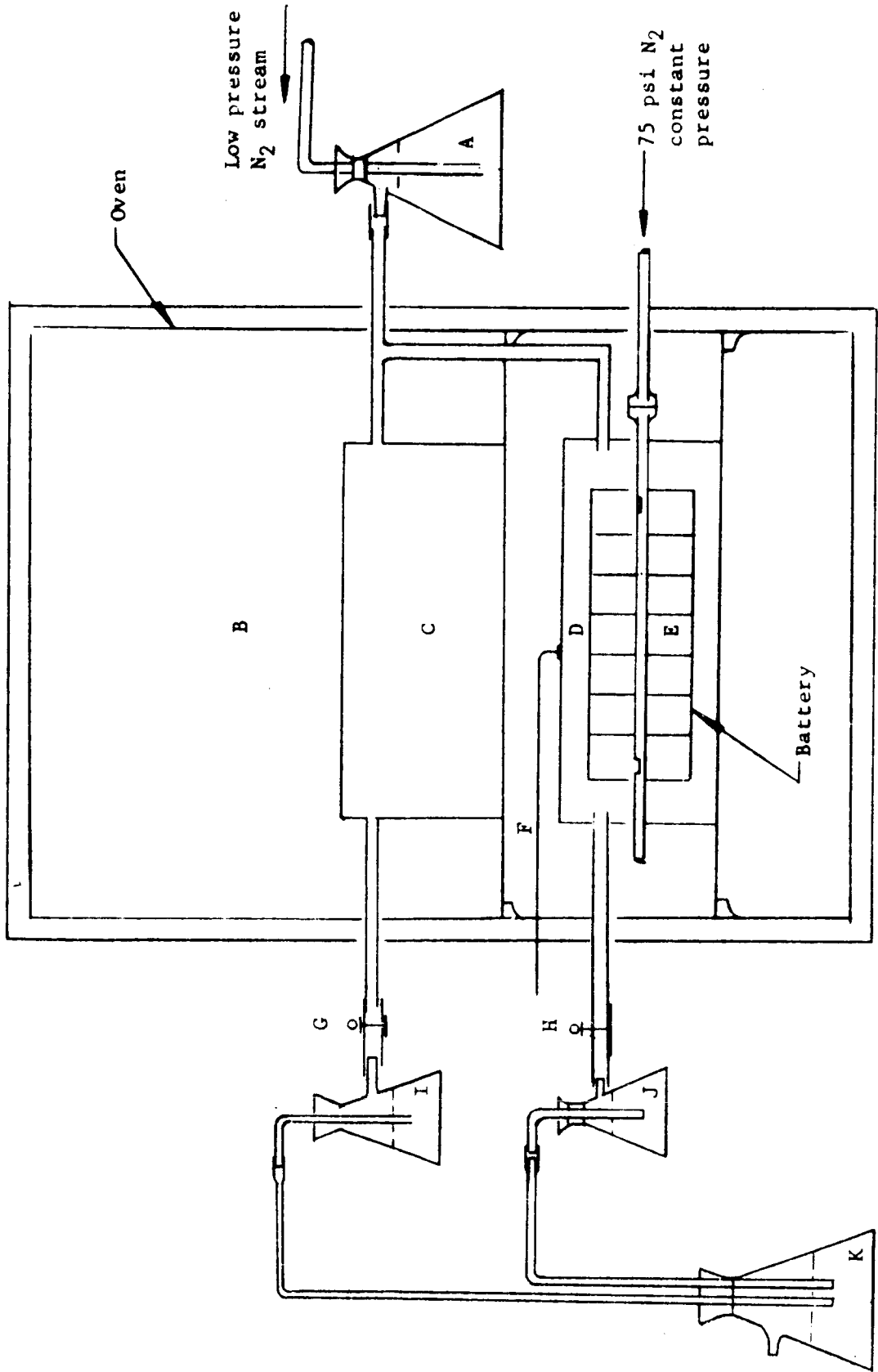


Figure 3. Permeability Test Apparatus

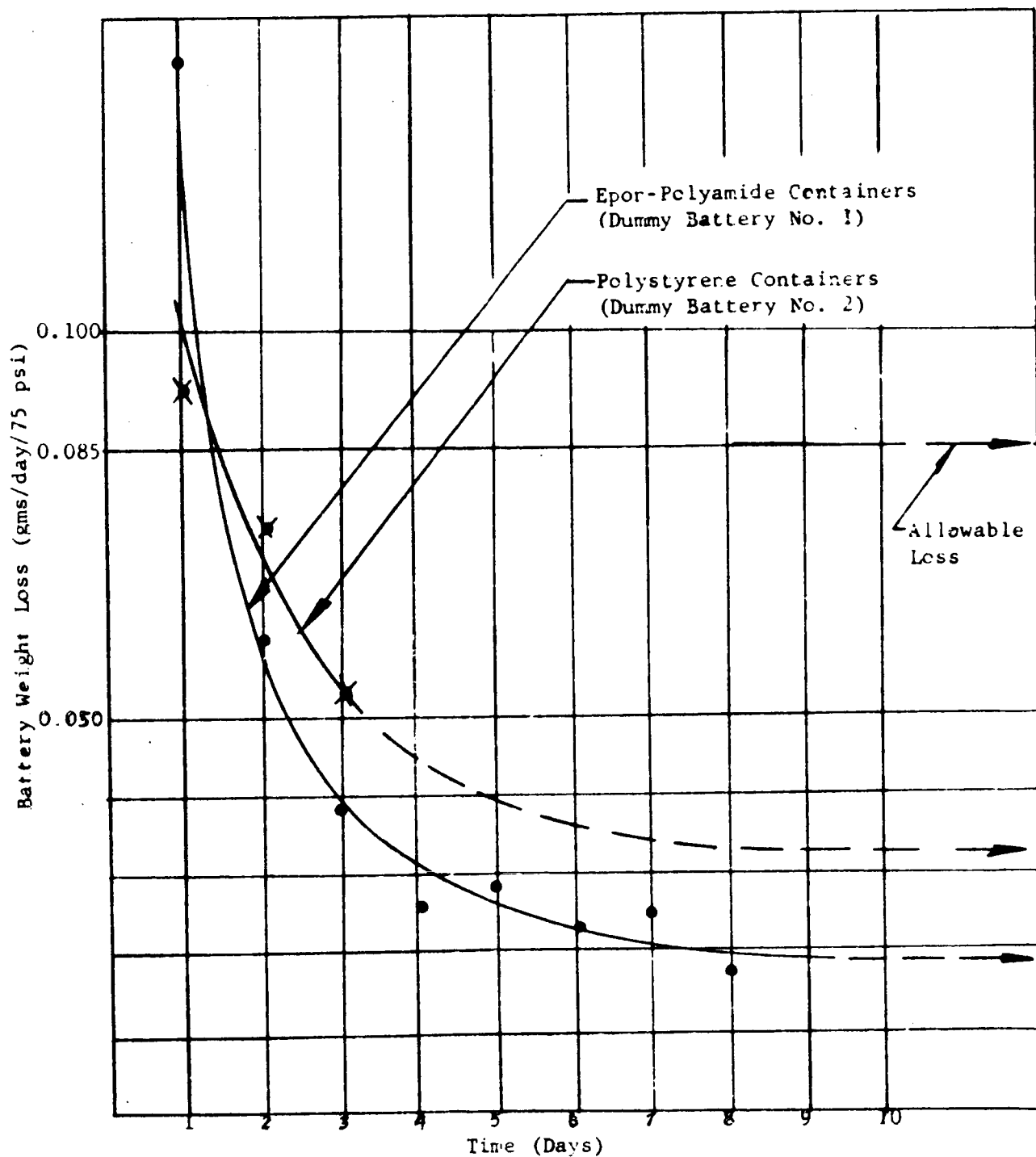


Figure 4. KOH Permeability Test

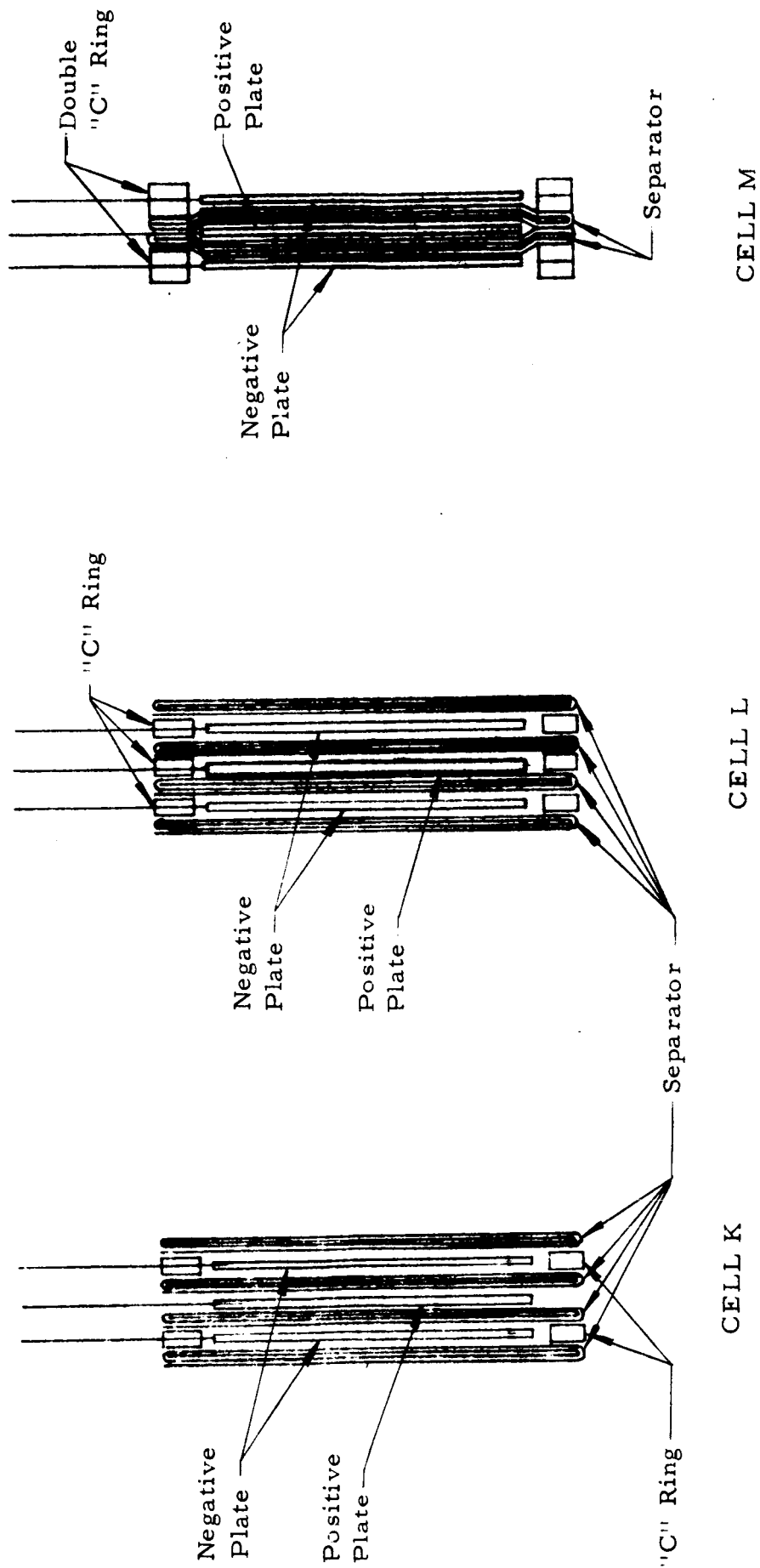
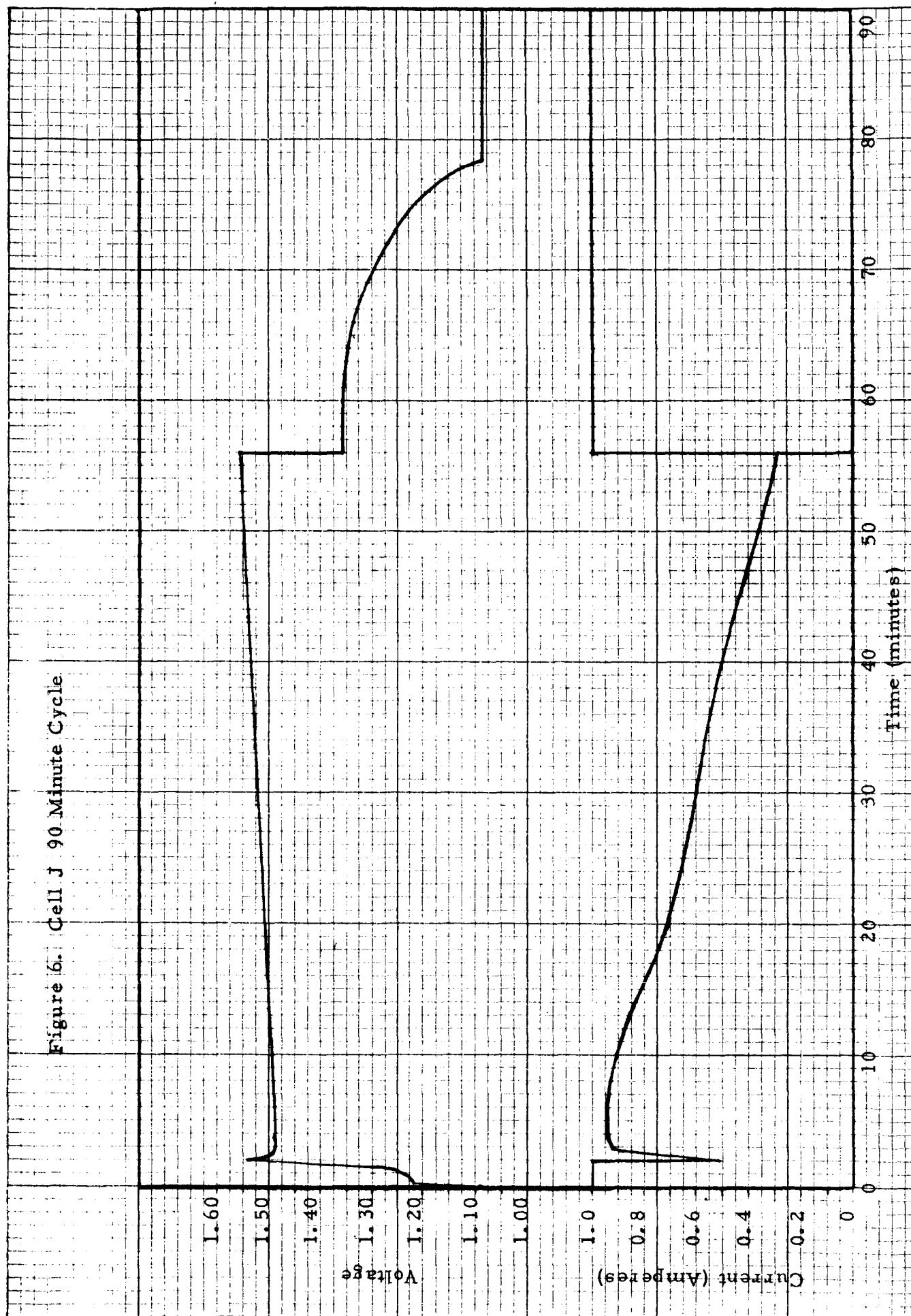


Figure 5. Various Cell Constructions

Figure 6. Cell J 90 Minute Cycle



K&S 10 X 10 TO THE INCH 359T 5  
KEUFFEL & ESSER CO. MADE IN U.S.A.  
ALBANY, N.Y. 12206

Figure 7. Cell 1, 3 Hour Cycle



Figure 8. Cell M, Typical Voltage Curve, 3 Hour Cycle



Figure 9. Cell M, Typical Voltage Curve, 4 Hour Cycle

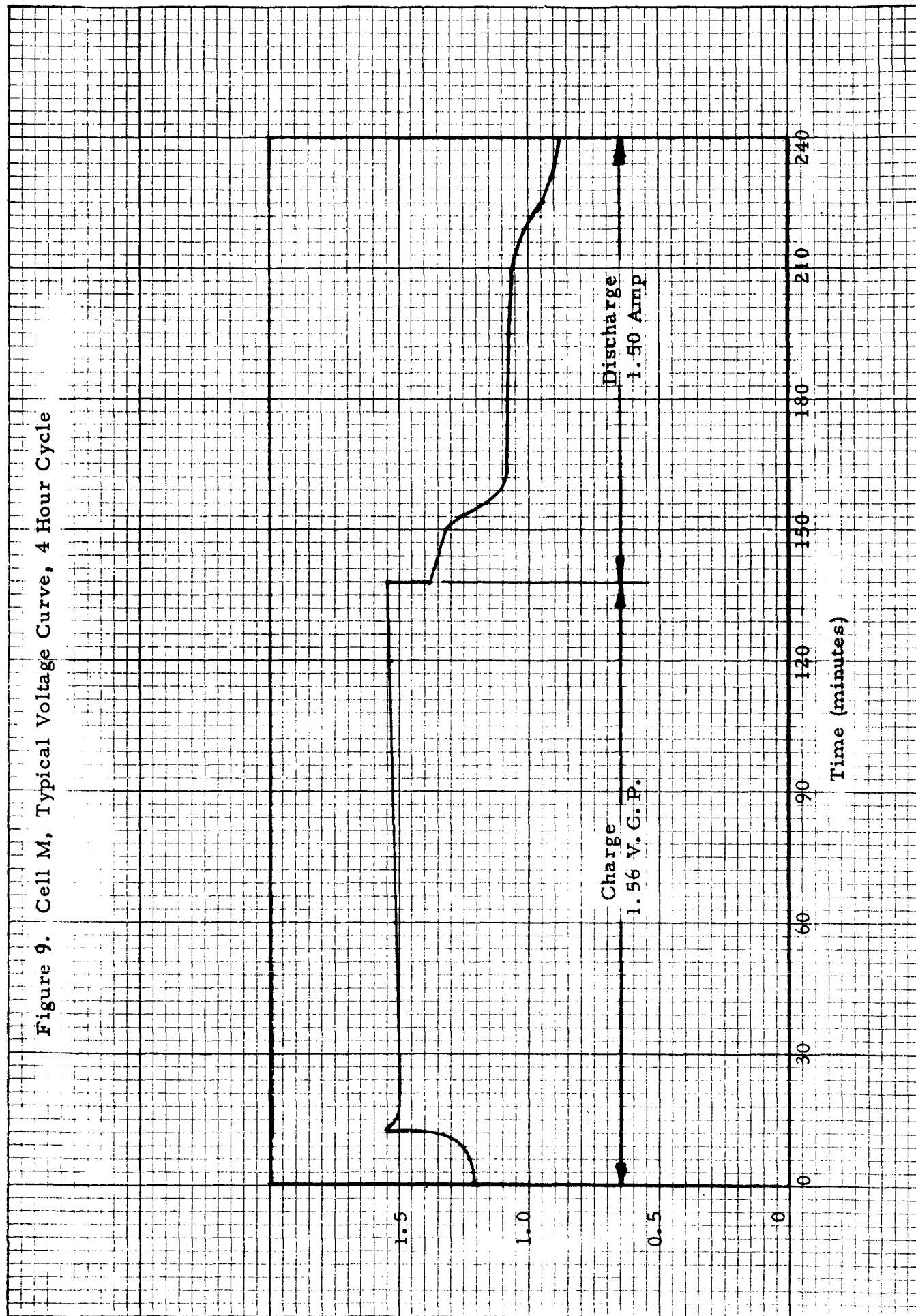
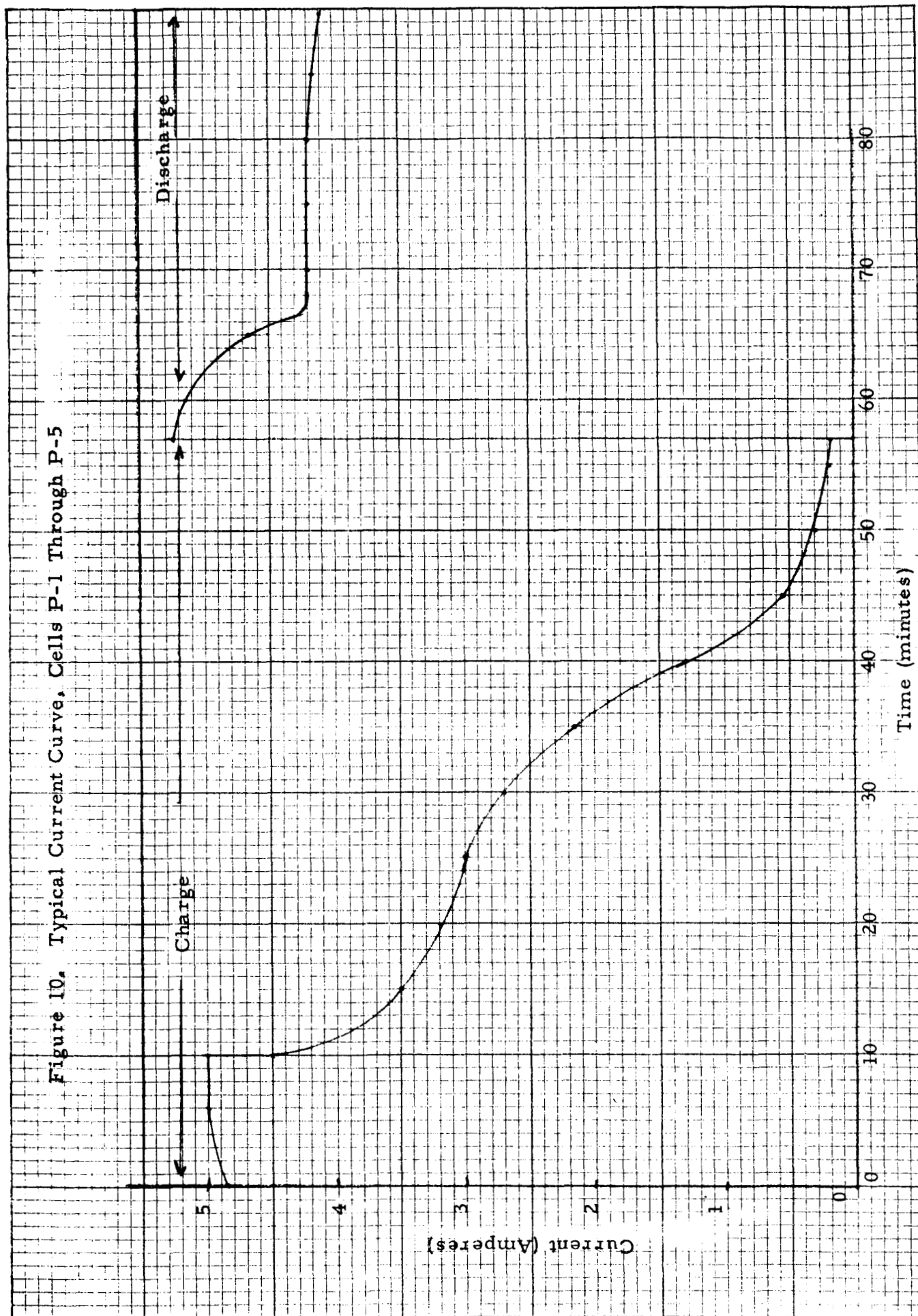


Figure 10. Typical Current Curve, Cells P-1 Through P-5



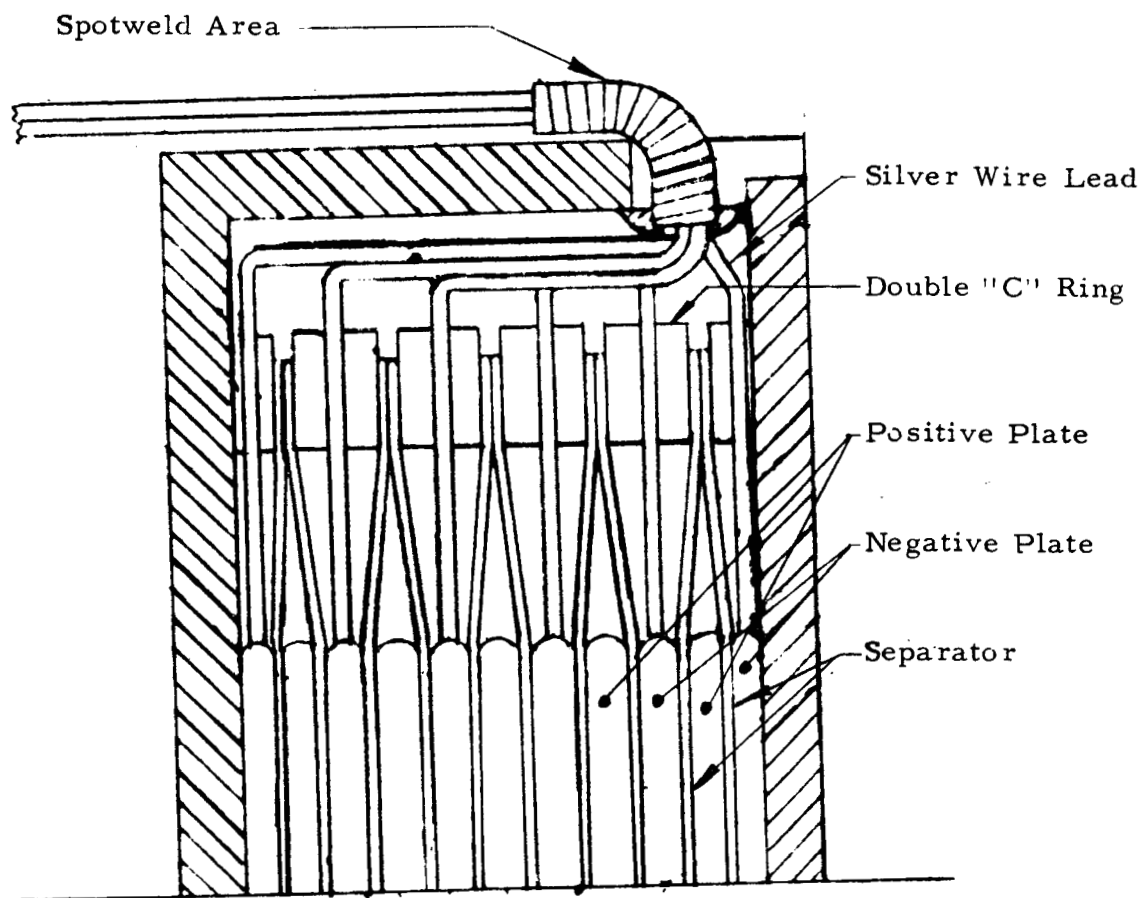


Figure 11. Final Cell Assembly

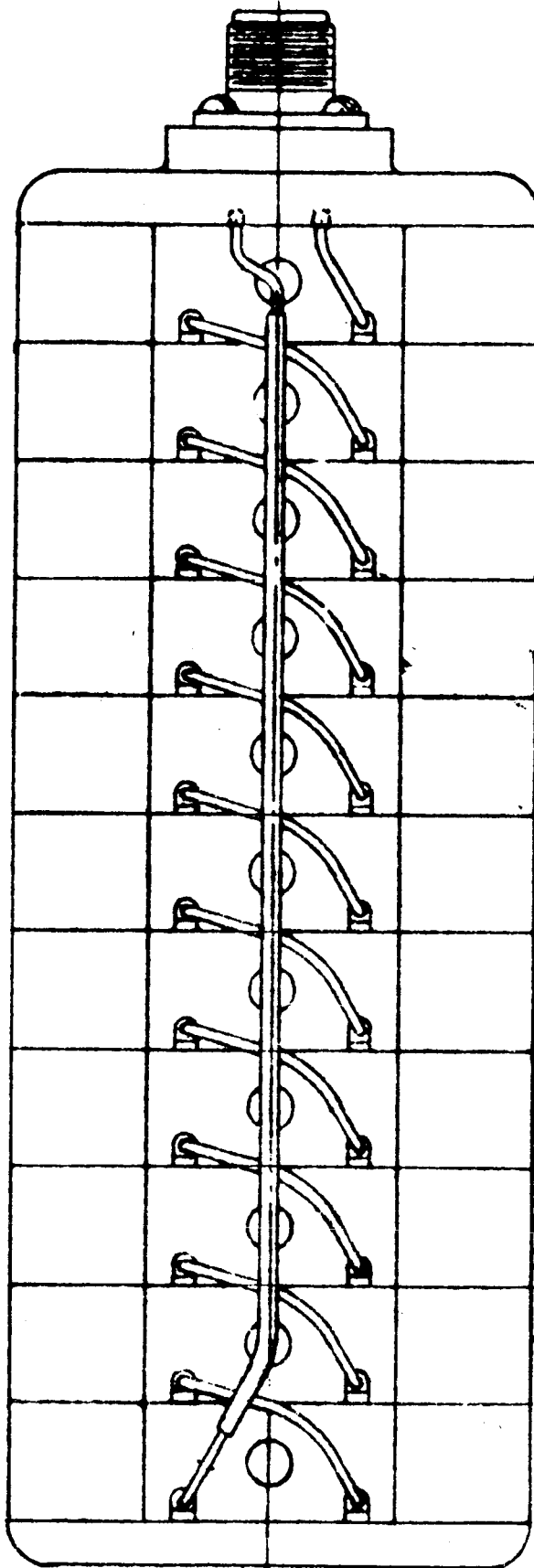


Figure 12. Final Assembly Prior to Winding

SILVER-CADMIUM BATTERY

TEST PROCEDURE


NUMBER 60219

DATED  
10 December 1962

CONTRACT NUMBER NAS5-1431

POWER SOURCES DIVISION  
TELECOMPUTING CORPORATION

Prepared by:

  
R. J. Balthazar  
Test Engineer

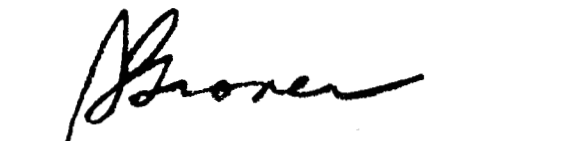
Approved by:

  
J. Rhyne  
Chief Electrochemist

Approved by:

  
T. W. O'Grady  
Chief Test Engineer

Approved by:

  
S. Groner  
Director of Engineering

1.0 REFERENCES

- 1.1 Cook Battery Company Proposal Number 483A.
- 1.2 Mil-E-5272C (ASG) Environmental Testing.
- 1.3 NASA Contract Number NAS5-1431.

2.0 SCOPE

This specification covers the methods and conditions which govern the electrical and environmental testing of batteries manufactured under the referenced contract.

3.0 NUMBER OF BATTERIES TO BE TESTED

- 3.1 Two groups of four batteries (eight (8) batteries total), shall be tested to determine compliance with the requirements specified herein.
  - 3.1.1 Three batteries from each group shall be cycled according to the requirements of Paragraphs 5.0 through 5.4 of this specification.
  - 3.1.2 One battery from each group shall be subjected to the environmental tests outlined under Paragraphs 6.0 through 6.7.2 of this specification.

4.0 TEST CONDITIONS

- 4.1 All tests shall be conducted at local atmospheric pressure, room (ambient) temperature, relative humidity 90% or less, and in a vertical position ( $Z_1$  axis up), unless otherwise specified.
- 4.2 Each battery specified in Paragraph 3.1.2 shall be potted (ends only) in a 3.5 inch O.D., 11 gauge, 8.5 inch long steel tube with a rigid material.
  - 4.2.1 Prior to potting, the battery shall be covered with one layer of Scotch tape to prevent adherence of the potting material to the battery casing.

- 4.3 Any evidence of a change which in any manner prevents the battery from meeting functional, maintenance or other requirements of service life shall be a ~~criterion~~ for considering the specimen to have failed. Criteria for failure shall be those expressed in Paragraphs 7.0 through 7.4.

5.0 ELECTRICAL AND TEMPERATURE TEST OF SIX BATTERIES

- 5.1 The temperature-electrical cycle test regime shall be as follows:

- 5.1.1 Twenty-five conditioning cycles at rates and times determined by the Project Engineer shall be applied at room temperature prior to the tests described in subsequent paragraphs.

5.1.2	Temperature (°F)	Number of cycles	Cycle Time (min. )		Cumulative Cycles
			Charge	Discharge	
	78	96	55	35	121
		1	1405	35	122
	113	96	55	35	218
		1	1405	35	219
	78	96	55	35	315
		1	1405	35	316
	5	96	55	35	412
		1	1405	35	413

- 5.1.3 Continued cycle testing shall be at room temperature and at the 55-minute charge - 35-minute discharge cycle unless otherwise specified by the Project Engineer.

- 5.2 Three batteries shall be tested per the schedule of Paragraph 5.1, with discharge to be made through 3 ohms fixed resistance (4.0 amperes nominal), and with charge to be applied at a current limited, constant potential of 17.6 volts (maximum) for a minimum of 413 cycles.

- 5.3 Three batteries shall be tested per the schedule of Paragraph 5.1, with discharge to be made through 6 ohms fixed resistance (2.0 amperes nominal), and with charge to be applied at a current limited, constant potential of 17.6 volts (maximum) for a minimum of 413 cycles.

6.0 ENVIRONMENTAL TESTS

6.1 One battery from each group (2 batteries total) shall be tested under the following environments and conditions:

6.1.1 A helium leak test, as specified in Paragraph 6.7, shall be conducted on the specimen (fully charged) prior to the position test (Paragraph 6.2), after the vacuum test (Paragraph 6.3), and after the shock test (Paragraph 6.6).

6.1.2 Prior to the start of the environmental tests, the specimen shall have completed a minimum of 100 charge-discharge cycles as specified in Paragraph 6.1.3.

6.1.3 The specimen shall be discharged through a fixed resistance of 3 ohms (2.0 amperes nominal) for 35 minutes and shall be charged at a current limited, constant potential of 17.6 volts (maximum) for 55 minutes.

6.1.4 After each environmental test, unless otherwise specified, the specimen shall be given a minimum of 16 cycles of electrical tests as specified in Paragraph 6.1.3 to check for any deterioration or change in performance which may be due to the environmental test.

6.2 Position Test

6.2.1 The specimen shall be electrically cycled as specified in Paragraph 6.1.3 for six hours in each of the following positions (Reference Figure 1):

Six hours (4 cycles) with  $Y_1$  axis up.

Six hours (4 cycles) with  $X_1$  axis up.

Six hours (4 cycles) with  $Z_2$  axis up.

6.3 Vacuum Test

6.3.1 The specimen shall be subjected to a vacuum of at least  $6.0 \times 10^{-2}$  mm Hg for a minimum of 72 hours while functioning in accordance with Paragraph 6.1.3.

6.4 Vibration Test (Operative)

6.4.1 The potted specimen shall be attached to a rigid fixture capable of transmitting the vibration conditions specified herein.

- 6.4.2 The battery shall be charged at a constant potential of 17.6 volts until the current flow is less than 0.2 amperes, and shall be discharged through 6 ohms resistance (2.0 amperes nominal) to a minimum voltage equal to 8.8 volts.
- 6.4.3 Vibration tests shall be conducted during the discharge portion of the electrical function test only, as per Paragraph 6.4.2.
- 6.4.4 The amplitude of applied vibration shall be monitored on the test fixture near the specimen mounting points.
- 6.4.5 The specimen shall be cycled from 5 to 3000 cps and back to 5 cps in a period of 9 minutes at an acceleration of + 20 g with a double amplitude of 0.4 inches. Crossover shall be at 31 cps. Specimen shall be vibrated in the above manner along each of three mutually perpendicular axes. The rate of frequency change shall be logarithmic.
- 6.5 Acceleration Test (Operative)
  - 6.5.1 The specimen shall be subjected to a steady acceleration of 20 g for one minute along each of its six directions (i.e., along both directions of its three mutually perpendicular axes) by a centrifuge (see Figure 1 for axial directions).
    - 6.5.1.1 The acceleration of 20 g applies to the geometric center of the specimen.
  - 6.5.2 The acceleration test shall be conducted during the discharge portion only of the electrical function test as specified in Paragraph 6.1.3. The discharge shall be started a minimum of one minute preceding acceleration and run continuously (except it is permissible to stop discharge for position change) through all acceleration plus five minutes after acceleration test.
- 6.6 Shock Test (Non-Operative)
  - 6.6.1 The specimen shall be in a charged condition.
  - 6.6.2 The specimen shall be subjected to 18 impact shocks of 40 g acceleration, each shock impulse having a time duration of  $11 \pm 1$  milliseconds reaching maximum acceleration at approximately 5.5 milliseconds.

6.6.3 The intensity shall be within  $\pm 10\%$  when measured with a filter having a band-width of  $\bar{5}$  to 100 cycles per second.

6.6.4 The shocks shall be applied in the following directions:

Vertically, three shocks in each direction of the Z axis; parallel to the major horizontal axes, three shocks in each direction of the X axis; parallel to the minor horizontal axes, three shocks in each direction of the Y axis.

6.6.5 After the shock test is completed the battery shall be cycled according to Paragraph 6.1.3.

6.7 Helium Leak Test

6.7.1 The unit shall be tested for leaks by a mass-spectrometer-type helium leak detector according to SPS 160A, which specifies that a 90 - 10 nitrogen - helium mixture be introduced into the specimen prior to sealing, and that a vacuum be pulled externally into the helium mass-spectrometer.

## 7.0 CRITERIA OF FAILURE

7.1 A battery may be considered to have failed electrically when a voltage less than 6.6 volts is reached prior to the completion of 35 minutes of discharge.

7.2 A battery may be considered to have failed structurally if there is noticeable leakage and/or rupture of the battery case.

7.3 If a battery failure occurs due to the malfunction of the test equipment without any structural damage taking place, the battery may be cycled manually. If performance has not been adversely affected, the battery may be returned for testing.

7.4 An analysis of each failed battery shall be made by the Project Engineer and recorded on the failure analysis form that is attached herein.

## 8.0 MAXIMUM ALLOWABLE TOLERANCES ON TEST CONDITIONS AND EQUIPMENT

The maximum allowable tolerances on test conditions and equipment shall be as follows:

Temperature:	$\pm 2^{\circ}\text{C}$ (exclusive of accuracy of instruments)
Vibration Amplitude:	$\pm 10\%$
Vibration Frequency:	$\pm 2\%$
Acceleration Force:	$\pm 10\%$
Shock Force:	$\pm 10\%$
Vacuum Pressure:	$\pm 10\%$
Voltage Regulation:	$\pm 1\%$
Current Resistance:	$\pm 1\%$
Time:	$\pm 15$ seconds

## 9.0 DATA COLLECTION

9.1 Life cycle, position and vacuum tests, Paragraph 5.0, 6.2 and 6.3.

9.1.1 Each battery voltage shall be monitored and recorded at least once every two minutes.

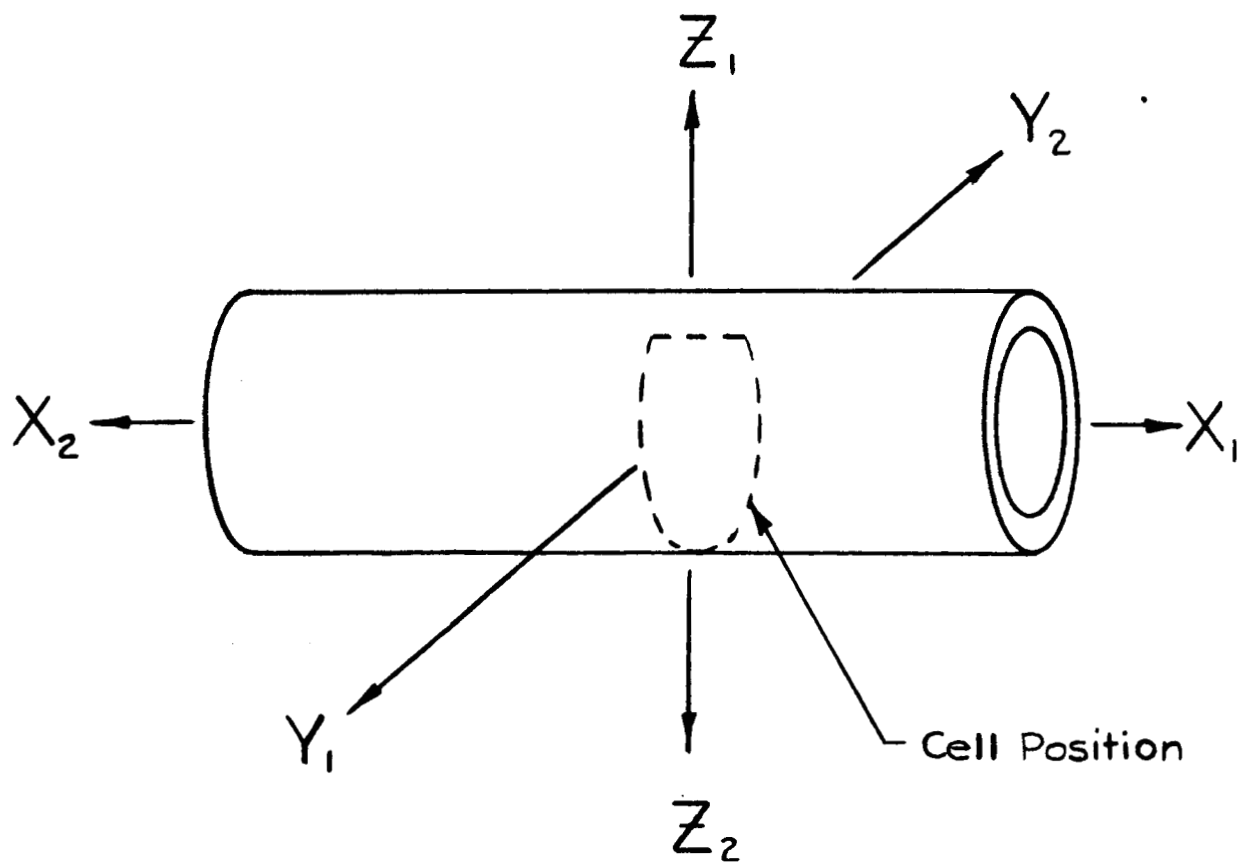
9.1.2 Discharge resistances for each battery shall be recorded twice each working day.

9.1.3 Test progress and charges shall be recorded on the cycle record sheets.

9.2 Operating Vibration Test

- 9.2.1 Voltage monitoring and recording of each battery shall be continuous on a chart at a speed of not less than three inches per minute, and recorded as designated on Cycling Record.
- 9.3 Acceleration
  - 9.3.1 Voltage and current monitoring and recording of each battery shall be continuous on a chart at a speed of not less than 12 inches per minute, and recorded as designated on Cycling Record.
- 9.4 Leak Rate
  - 9.4.1 The leak rate shall be recorded prior to the position test (Paragraph 6.2), after the vacuum test (Paragraph 6.3, and after the shock test (Paragraph 6.6).

FIGURE 1



ENVIRONMENTAL TEST RESULTS

Vibration (Operative), Paragraph 6.4

		<u>X Axis</u>	<u>Y Axis</u>	<u>Z Axis</u>
Date	Mo., Day, Yr.			
Battery	No.			
Cycle	No.			
Temperature	°F			
Model and Serial Numbers of Instruments Used:				

Test Remarks \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Tested by \_\_\_\_\_ Title \_\_\_\_\_

ENVIRONMENTAL TEST RESULTS

Acceleration (Operative), Paragraph 6.5

<u>Reading</u>	<u>Units</u>	<u>X Axis</u>	<u>Y Axis</u>	<u>Z Axis</u>
		Fwd/Rvs	Fwd/Rvs	Fwd/Rvs
Date	Mo., Day, Yr.			
Battery	No.			
Cycle	No.			
Temperature	°F			
Centrifuge Arm	In.			
Rotation Speed	Revs. /min.			
Acceleration	g			

Model and Serial  
Numbers of  
Instruments Used

Test Remarks: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Tested by: \_\_\_\_\_ Title: \_\_\_\_\_

ENVIRONMENTAL TEST RESULTS

Shock (Non-Operative), Paragraph 6.6

<u>Reading</u>	<u>Units</u>	<u>X Axis</u> Fwd/Rvs	<u>Y Axis</u> Fwd/Rvs	<u>Z Axis</u> Fwd/Rvs
Date	Mo., Day, Yr.			
Battery	No.			
Cycle	No.			
Temperature	°F			
Shock Impulse Duration	Shock No. 1 - Msec. 2 - Msec. 3 - Msec.			
Maximum Impact Acceleration	Shock No. 1 - g 2 - g 3 - g			
Acceleration Reached at 5.5 Msec.	Shock No. 1 - g 2 - g 3 - g			

Model and Serial  
Numbers of  
Instruments Used

Test Remarks: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Tested by: \_\_\_\_\_ Title: \_\_\_\_\_

### BATTERY FAILURE ANALYSIS

Environmental Test \_\_\_\_\_ Paragraph \_\_\_\_\_

Battery No. \_\_\_\_\_ Cycle No. \_\_\_\_\_ Temperature \_\_\_\_\_ °F

Charge

Discharge

Time \_\_\_\_\_ min.

Time \_\_\_\_\_ min.

Constant Potential \_\_\_\_\_ volts

Resistance \_\_\_\_\_ ohms

Nominal Current \_\_\_\_\_ amperes

Date of Failure \_\_\_\_\_.

Criteria for Terminating Test \_\_\_\_\_

Visual Inspection (battery)

Remarks

Case Leakage

Case Distortion

Seal Leakage

Excessive Heat

Visual Inspection (cells)\*

Position Number (pos. to neg.)    1    2    3    4    5    6    7    8    9    10    11

Mfg. Number

Case Leakage

Case Distortion

Seal Leakage

Excessive Heat

\* ( ✓ - Good: X - Damaged)

Signature \_\_\_\_\_ Title \_\_\_\_\_ Date \_\_\_\_\_

### CELL AUTOPSY

Battery No. \_\_\_\_\_ Cell No. \_\_\_\_\_  
Terminals \_\_\_\_\_  
Tabs \_\_\_\_\_  
Negatives \_\_\_\_\_  
Positives \_\_\_\_\_  
Separation \_\_\_\_\_  
Electrolyte \_\_\_\_\_  
Case \_\_\_\_\_

Separator Ag Content (mg/layer)	No. 1	_____	No. 5	_____
	No. 2	_____	No. 6	_____
	No. 3	_____	No. 7	_____
	No. 4	_____		

Remarks \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Signature: \_\_\_\_\_ Title: \_\_\_\_\_ Date: \_\_\_\_\_

Battery No. \_\_\_\_\_ Cell No. \_\_\_\_\_  
Terminals \_\_\_\_\_  
Tabs \_\_\_\_\_  
Negatives \_\_\_\_\_  
Positives \_\_\_\_\_  
Separation \_\_\_\_\_  
Electrolyte \_\_\_\_\_  
Case \_\_\_\_\_

Separator Ag Content (mg/layer)	No. 1	_____	No. 5	_____
	No. 2	_____	No. 6	_____
	No. 3	_____	No. 7	_____
	No. 4	_____		

Remarks \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Signature: \_\_\_\_\_ Title: \_\_\_\_\_ Date: \_\_\_\_\_

Leak Rates

cc/sec.

Prior to Position Test (Para. 6.2)

\_\_\_\_\_

Remarks: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Signature: \_\_\_\_\_

Title: \_\_\_\_\_

Date: \_\_\_\_\_

Following Vacuum Test (Para. 6.3)

\_\_\_\_\_

Remarks: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Signature: \_\_\_\_\_

Title: \_\_\_\_\_

Date: \_\_\_\_\_

Following Shock Test (Para. 6.6)

\_\_\_\_\_

Remarks: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Signature: \_\_\_\_\_

Title: \_\_\_\_\_

Date: \_\_\_\_\_

**Specification Number**  
60219

**SHEET #**

BATTERY

[illegible]